V.—*Effects of the Drought of* 1870 *on some of the Experimental Crops at Rothamsted.* By J. B. Lawes, Esq., F.R.S., F.C.S., and J. H. Gilbert, Ph. D., F.R.S., F.C.S.

The rainfall of Great Britain is usually sufficient for the growth of a considerable variety of crops, in fairly abundant quantity. Indeed, so far at least as the growth of corn is concerned, our fears are of injury from an excess rather than from a deficiency of rain. It is only occasionally, and generally at long intervals, that a season of great drought occurs; and then it is that we forcibly realise how essential for luxuriant vegetation is an abundant supply of water.

Throughout the Midland, Southern, and Eastern portions of England, the year 1870, just past, has been characterised by a season of drought, commencing with the period when vegetation usually becomes active, and extending, with little intermission, to the time when its activity has upon the whole greatly diminished, and in the case of some crops entirely ceased. To find a parallel we must go back to 1844, or more than a quarter of a century. The summer of 1868 was, it is true, one of great drought; and, being hotter than that of 1870, it is not improbable that there was at some periods of it a greater deficiency of moisture in the soil than in the latter year. In fact, those who travelled through the Southern and Midland counties of England in July, 1868, will not soon forget the almost entire absence of green in the meadows, and the intense heat of the atmosphere, resembling more what we read of in tropical countries than the usual experience of our own summers. Although both the drought and heat were more extreme during the months of May, June, and July in 1868 than in 1870, the deficiency of rain commenced a month earlier and extended later last year; and hence, not only the first crops of grass and hay, but also the second growth, suffered much more in the season just past than in 1868.

It is only when crops are grown under precisely similar circumstances, as to manure and other conditions, for many years in succession, that we can obtain satisfactory data for studying the influence of variation of season on the amount and character of the produce. At Rothamsted, as is known to most of the readers of this Journal, numerous experiments on the growth of various crops, each grown year after year on the same land, with different descriptions of manure, the same description being applied year after year to the same plot, have been carried on without change for many years; in some cases reaching back as far as the drought of 1844, above referred to. Taking advantage of the results so obtained, it is proposed, in the present paper, to consider briefly :—

1. The probable amount of water exhaled during growth by some of our most important crops.

2. The source whence the required supply of water is obtained.

3. The difference of the effects of the drought of 1870 on the different experimental crops.

Amount of Water given off by Plants during Growth.

A series of experiments was commenced in 1849, and was continued for ten years, to determine the amount of water given off by plants during their growth, in relation to the amount of the various constituents they assimilated. Of agricultural plants, wheat, barley, and mixed grasses, as representatives of the Graminaceous family; beans, peas, and clover, of the Leguminous family; and swedes, white turnips, mangolds, potatoes, and artichokes, as root-crops, were thus experimented upon. Similar experiments were also made on the exhalation by evergreen and deciduous trees, six of each being selected.

The plan of experimenting was as follows:—Cylindrical vessels, first of glass and afterwards of zinc, 14 inches in depth, 9 inches in diameter, and holding about 40 lbs. of soil, were employed. Soil from the plot in the experimental wheat-field which had grown 10 successive crops without manure was selected. The general rule was to make three experiments with each description of plant; one with the above soil without further addition; one with the same soil with purely mineral manure added; and the third with the same soil and both mineral manure and ammonia-salts in addition. In the cases of wheat and barley, plants from three seeds, and of beans, peas, and clover, one plant only, were planted in each vessel. A glass plate, having a hole in the centre about three-quarters of an inch in diameter for the plants to grow through, and another smaller one, closed at pleasure by a cork, for the supply of water, were then firmly cemented upon the top of each vessel. One vessel, supplied with soil and fitted with a glass cover like the rest, was, however, always left without a plant, in order to ascertain the probable amount of evaporation from the surface of the soil itself, through the centre orifice, independently of growth; though, in the experiments with plants, the hole was always partially closed, by laying small pieces of glass over it as far as the stems would allow. Of course in experimenting with root-crops the holes in the glass covers were larger, but they were kept closed around the plants as far as possible, in the manner just described.

The vessel with its contents, weighing more than 40 lbs., was weighed from time to time, generally every ten days during active growth, by means of a delicate balance made for the purpose; which, though carrying so heavy a weight, was capable of indicating a change of a few grains. The plants were of course supplied with water as it was needed. The earlier results, both with agricultural plants and trees, are published in the 'Journal of the Horticultural Society of London,' and to the reports there given we must refer the reader for the details of the inquiry as far as they are yet recorded.*

Referring here only to the results obtained with some of the agricultural plants, it will be sufficient for our present purpose to summarise them as follows:—

1. The amount of water given off by the plants during growth was found to bear relation to the quantity of the total dry matter, or the total non-nitrogenous substance, fixed or assimilated; and within somewhat narrow limits the same relation was observed in the case of both graminaceous and leguminous corn-crops.

2. In relation to a given quantity of water exhaled, twice or three times as much nitrogenous substance is fixed by a leguminous, as by a graminaceous corn-crop.

3. In the growth and ripening of either graminaceous or leguminous corn-crops, probably on the average from 250 to 300 parts of water are given off for 1 part of total dry substance fixed or assimilated.

Before considering the application of this estimate to any special cases, it may be well to give an illustration of its bearing in general terms. Several plots in the experimental wheat-field give an average of about 3 tons of total produce (corn and straw) per acre per annum; and if we assume one-sixth of this to be water, we have remaining $2\frac{1}{2}$ tons of dry substance ripened by the end of July, or the middle of August, each year; and if we further assume that 300 parts of water may be exhaled for 1 part of dry substance fixed, we have $300 \times 2{\cdot}5 = 750$ tons of water evaporated per acre by the growth of such a crop.

Owing to the difficulty of eliminating surface evaporation other than through the growing herbage, in experiments on the exhalation from a sod of mixed grasses, we cannot so safely adopt a figure to represent the probable average amount of water given off for 1 part of dry substance fixed in their case as in that of their ripened allies, wheat and barley. We will

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* 'Experimental investigation into the amount of water given off by plants during their growth, especially in relation to the fixation and source of their various constituents.'—('Jour. Hort. Soc. Lond.,' vol. v. part i. 1850.)

'Report upon some experiments undertaken at the suggestion of Professor Lindley, to ascertain the comparative evaporating properties of Evergreen and Deciduous Trees.'—('Jour. Hort. Soc. Lond.' vol. vi. parts iii. and iv. 1851.)

assume, however, for the purpose of illustration, that in the growth of hay, as in that of the grain-crops, about 300 parts of water will be exhaled for 1 part of dry substance assimilated; and since one of the experimental plots of meadow land at Rothamsted has given an average, over fifteen years, of 3 tons of hay, or about 2½ tons of dry substance per acre per annum, its growth would again represent an exhalation of about 750 tons of water per acre per annum—but extending in this case not later than to the middle or end of June.

We will now adduce some special cases illustrating the amount of water exhaled by different crops, and their dependence on the rainfall of the period of active growth, or on the supplies of moisture previously accumulated within the soil.

Results relating to the Growth of the Hay-crop.

The following Table (I.) shows the amount of hay obtained per acre each year for fifteen years in succession (1856-1870):—

1. Without manure.
2. With mixed mineral manure and 400 lbs. ammonia-salts per acre per annum.
3. With mixed mineral manure and 550 lbs. nitrate of soda per acre per annum (thirteen years only, 1858-1870).

The Table also shows, side by side with the records of produce, the amount of rain, in inches, which fell at Rothamsted each year

Table I.

Years.	Hay per Acre.				Rain at Rothamsted.			
	Without Manure.	Mineral Manure and Ammonia-salts.	Mineral Manure and Nitrate of Soda.	Mean.	April.	May.	June.	Total.
	Cwts.	Cwts.	Cwts.	Cwts.	Inches.	Inches.	Inches.	Inches.
1856	22½	56¾	..	39⅝	2·61	4·70	1·91	9·22
1857	25½	57¼	..	41⅜	2·16	1·10	2·21	5·47
1858	22	64	50⅜	45½	2·58	2·55	0·96	6·09
1859	22⅝	55¼	54¼	44	2·70	2·09	2·72	7·51
1860	24⅝	50¼	49⅞	41⅝	1·94	4·30	6·26	12·50
1861	25⅜	56⅜	52⅜	44¾	1·28	1·04	2·98	5·30
1862	27¼	57⅛	51	45⅛	2·84	2·91	3·41	9·16
1863	20⅜	53¾	58¼	44⅛	0·96	1·01	4·60	6·57
1864	24	50¼	60⅞	45	1·25	1·88	1·79	4·92
1865	11½	34½	47¼	31⅛	0·47	3·05	0·68	4·20
1866	23¾	44¼	58¾	42¼	1·95	1·24	4·51	7·70
1867	29¾	48	64⅛	47¼	2·82	3·35	1·06	7·23
1868	17½	59⅛	69	48½	2·19	0·73	0·37	3·29
1869	38	68¾	76⅛	61	2·13	3·23	1·07	6·43
1870	5¾	29½	56¼	30½	0·46	1·35	0·98	2·79
Average	22¾	52⅜	57⅝	43½	1·89	2·30	2·37	6·56

during the months of April, May, and June, which may be considered as including the period of active growth of the hay-crop.

Although there is much to be learnt from the results brought together in the foregoing Table, much more information than is there given would be required—as to the difference in the character of the herbage produced under the different conditions, the distribution of the rain, the degree and range of temperature, and the mutual adaptations of moisture, heat, and stage of growth) of the plants—to enable us to account for all the fluctuations in the amounts of gross produce which the records show.

It is seen at a glance that the fluctuations from year to year in the amounts of produce without manure, though doubtless greatly dependent on the quantity and distribution of the rain falling during the period of active growth, by no means correspond with the fluctuations in the total amount of rain during the three months. Thus, the average fall for the three months is 6·56 inches, and the average produce of hay without manure is $22\frac{3}{4}$ cwts. But we have, with almost exactly the same total amount of rain during the same period in 1863 (6·57 inches), only $20\frac{3}{8}$ cwts. of hay; whereas, with even rather less (6·43 inches), in 1869, we have the heaviest produce obtained in any one of the series of 15 years, namely, 38 cwts. The fact is that, coincidently with the small produce of 1863, less than one-third of the total rainfall of the three months occurred during the first two months of the period; whilst, coincidently with the very heavy produce in 1869, there was considerably more than the average fall of rain in both April and May, and less than half the average fall in June; the result being that more than five-sixths of the total fell during the first two of the three months, when its influence upon the growth would be the greatest. Again, the heaviest total fall within the growing period was in 1860, when there was nearly double the average amount, whilst the produce only exceeded the average by less than 2 cwts. of hay; the facts being, that about half the total amount fell in June, that is, not until the last month of growth; and that the temperature was very unusually low almost throughout the period of active vegetation.

The lowest amounts of produce were—$17\frac{1}{2}$ cwts. in 1868, $11\frac{1}{2}$ cwts. in 1865, and only $5\frac{3}{4}$ cwts. in 1870. This last, the lowest amount in the series, is coincident with the smallest amount of total rain over the three months throughout the fifteen years, namely 2·79 inches. With only 3·29 inches in the three months of 1868, there was a produce of $17\frac{1}{2}$ cwts., but with 4·2 inches in 1865, there was only $11\frac{1}{2}$ cwts. But whilst, in the latter year, there was in April only about one-fourth the average fall, and very high temperature, there was during the same month in 1868 more than the average fall, and about the average temperature.

Turning to the columns of produce obtained by the two artificial manures, it is seen that, whilst in the earlier years the mineral manure and ammonia-salts gave more hay than the mineral manure and nitrate of soda, in the later years the mineral manure and nitrate yielded considerably more than the mineral manure and ammonia-salts. It is obvious, therefore, that the fluctuations in the produce are dependent on other conditions than the variations in external or climatic circumstances alone. It will come within the special province of our subject to explain this further presently; but, in passing, we may here remark that the character of the mixed herbage in regard to the distribution of plants, and the prevalence of individual species, was very widely different in the two cases; and the dependence of the amount of produce on external supplies of moisture will, of course, be greatly measured by the degree of root range, and the consequent command of the moisture within the soil itself, of the particular species favoured.

These few observations will be sufficient to indicate some of the points of interest which the study of the subject in detail is calculated to elucidate, and to show the complexity of the conditions upon which the final result—the weight of hay—depends.

We will now turn to the more special object of the present communication.

The following are the amounts of hay obtained per acre in 1870, on each of the three plots already referred to, and also the average amounts over 15 years without manure, and with mineral manure and ammonia-salts, and over 13 years with mineral manure and nitrate of soda.

Table II.

	Hay per Acre.		
	1870.	Average 15 (or 13) Years, 1856-70.	Deficiency in 1870.
	Cwts.	Cwts.	Cwts.
Without manure	$5\frac{3}{4}$	$22\frac{3}{4}$	17
Mineral manure and ammonia-salts ..	$29\frac{1}{2}$	$52\frac{3}{8}$	$22\frac{7}{8}$
Mineral manure and nitrate of soda ..	$56\frac{1}{4}$	$57\frac{5}{8}$	$1\frac{3}{8}$

Thus, under the influence of the extraordinary drought of 1870, there was a variation in the amount of produce on closely adjoining plots, from only $5\frac{3}{4}$ cwts. of hay without manure, to

$29\frac{1}{2}$ cwts. with mineral manure and ammonia-salts, and to $56\frac{1}{4}$ cwts. with mineral manure and nitrate of soda. Indeed, without manure there was not only less produce than in any preceding year of the fifteen, but only about one-fourth the average amount. With mineral manure and ammonia-salts there was again considerably lower produce than in any other of the fifteen years with the same manure, and a deficiency of nearly 23 cwts. compared with the average. Notwithstanding this, we have the remarkable result of 2 tons 16 cwts. of hay produced by mineral manure and nitrate of soda, or only about $1\frac{1}{4}$ cwt. less than the average amount by that manure; about $2\frac{1}{2}$ tons more than without manure, and $1\frac{1}{3}$ ton more than by the mixture of mineral manure and an amount of ammonia-salts containing about the same quantity of nitrogen as the nitrate.

On the assumption that probably about 300 parts of water pass through the plants for one part of dry substance fixed, about 700 tons of water must have been exhaled by the herbage during the growth of the 56 cwts. of hay. But, reckoning an inch of rain to represent a fall of 101 tons per acre, the 2·79 inches which fell in 1870 during April, May, and June, the period of active vegetation, could only supply 282 tons of this, provided (which would not be the case) none of it was lost by drainage, and none of it passed off by evaporation otherwise than through the plants themselves. On the same assumptions, the amount which fell would be about 160 tons less than sufficient for the requirements of the crop grown by mineral manure and ammonia-salts, but more than three times as much as would be required by the growth of the unmanured produce.

So striking was the difference in the effect of the drought on two plots side by side, the one manured with mineral manure and a given quantity of nitrogen in the form of ammonia-salts, and the other with the same mineral manure and the same quantity of nitrogen, but the latter in the form of nitrate of soda instead of ammonia-salts, that it was decided, on the removal of the crop, to determine the quantities of water existing in the soil of the three plots to a depth somewhat greater than the lowest to which roots could be traced; and also to observe the difference in the development and distribution of the roots, if any, on the different plots. Accordingly, on July 25 and 26, 1870, samples of soil were taken from the three plots to the depth of 54 inches in each case, roots having been traced on one of them to within a few inches of that depth.

The plan of collecting and preparing samples of soil for analysis will be understood from the following description of the process in the present instance: A square yard, comprising a fair proportion of the species contributing to the bulk of the herbage, having been carefully selected on each plot, a case or frame, open at the top and bottom, made of strong sheet-iron, 6 inches square by 9 inches deep (but which may be of any desired size), was driven into the ground in the centre of the square, level with the surface. The enclosed soil was then dug out exactly to the depth of the case. The soil around the case, to the extent of the square yard selected, was then removed to the level of the bottom of it; it was again driven down, and its contents carefully taken out; and so on, the process was repeated, until the desired depth was attained. The determination of the water in the samples being the special object of the experiments in question, the exact weight of the soil was taken immediately on removal, so that any loss of moisture by evaporation during preservation, or preparation for analysis, might be duly taken account of. The whole was then broken up, the stones sifted out, separating first those which did not pass a 1-inch sieve, next a ½-inch, and finally a ¼-inch sieve being used. The mould, or soil, passing the ¼-inch sieve was weighed, a proportional part of it finely powdered for analysis and re-weighed. In the soils so prepared, the loss of moisture, at different temperatures, has been and the nitrogen and some other constituents will be determined.

The following Table shows the percentage of moisture, as determined by the loss when dried at 212° Fahr., inclusive of that by evaporation during preparation for analysis, in the soil from each of the three plots of the experimental meadow-land, at each depth to which the samples were taken:—

TABLE III.—MOISTURE in the Soil from Plots of Permanent Meadow Land differently Manured. Samples collected July 25–6, 1870.

Depth of Sample.	PERCENTAGES OF MOISTURE (Soils dried at 212° Fahr.).		
	Plot 3. Without Manure.	**Plot 9.** Mineral Manure and Ammonia-salts.	**Plot 14.** Mineral Manure and Nitrate of Soda.
First 9 inches	10·83	13·00	12·16
Second 9 inches	13·34	10·18	11·80
Third 9 inches	19·23	16·46	15·65
Fourth 9 inches	22·71	18·96	16·30
Fifth 9 inches	24·28	20·54	17·18
Sixth 9 inches	25·07	21·34	18·06
Mean	19·24	16·75	15·19

The results recorded in this Table are of great interest and significance; and they supply important data towards the explanation of the extraordinary difference in the amount of produce obtained on the different plots. It should be premised, however, that between the removal of the crops and the date of sampling the soils, in all nearly an inch of rain had fallen, perhaps affecting somewhat the actual percentages, but the relative amounts probably but little.

The first point to remark is, that the first 9 inches of soil of both the heavily manured, and more or less heavily cropped, plots contained a higher percentage of moisture than that of the unmanured and lightly cropped plot. But from that point downwards to a depth of 54 inches, and doubtless further still, the manured and more heavily cropped soils contained much less moisture than the unmanured; and the most heavily cropped soil, that of Plot 14, manured with mineral manure and nitrate of soda, contained considerably less than that of Plot 9, manured with mineral manure and ammonia-salts. And whilst at a depth of from 45 to 54 inches the unmanured soil contained 25 per cent. of moisture, that receiving mineral manure and ammonia-salts contained only 21·34 per cent.; and that receiving mineral manure and nitrate of soda only 18 per cent., or scarcely $\frac{3}{4}$ths as much as the unmanured soil at the same depth. To sum up the results, there is an average amount of moisture down to the depth of 54 inches, of $19\frac{1}{4}$ per cent. on the plot without manure, of only $16\frac{3}{4}$ per cent. on the plot manured with mineral manure and ammonia-salts, and of scarcely $15\frac{1}{4}$ per cent. on that manured with mineral manure and nitrate of soda, or only about $\frac{4}{5}$ths as much on the latter as on the unmanured plot.

The subsoil of this meadow land is a reddish yellow clay, interspersed with grey veins, and the specific gravity increases by about one-half from the surface down to the greatest depth taken. For our present purpose it will be a sufficiently near approximation to the truth to assume that down to the depth of 54 inches, the soil (exclusive of stones) weighed an *average* of 1,000,000 lbs. per acre for every 3 inches of depth, or an aggregate of 18,000,000 lbs. per acre to the depth of 54 inches. Adopting this estimate, and the percentages of moisture given in Table III., it results that down to the depth of 54 inches, or 4 feet 6 inches, the unmanured soil retained 1546, the soil of Plot 9, 1346, and that of Plot 14, 1221 tons of water. That is to say, to the depth of 4 feet 6 inches, the soil of Plot 9, manured with mineral manure and ammonia-salts, contained 200 tons, and that of Plot 14, manured with mineral manure and nitrate of soda, 325 tons less water per acre than that of the unmanured soil to the same depth; whilst, from the great difference in the percentage at the lowest depths taken in the three cases, there can be no doubt that the difference extended considerably deeper still.

Here, then, we have evidence of the source whence the manured crops derived the water required for their growth, over and above that supplied by the rain actually falling during the period of active vegetation. But the questions obviously arise—if the unmanured subsoil retained so much more water, why did the crop suffer from the drought so very much more than the manured crops? and why did the crop manured with mineral manure and ammonia-salts suffer so much more than that manured with mineral manure and nitrate of soda, and not avail itself so fully as did the latter of the stores of moisture within the soil? To gain some information on the points here suggested, careful examination was made of the distribution of species on the square yard of the plot selected, of the section of the soil and subsoil, and of the distribution of roots within them.

It should be stated that 53 species in all are found on the continuously unmanured plot; this great complexity of herbage being maintained in consequence of the little encouragement to luxuriance of any. On the other hand, by the application of mineral manure and ammonia-salts on Plot 9, and of mineral manure and nitrate of soda on Plot 14, for many years in succession, and the consequent great encouragement and predominance of certain individual species, the total number discernible has become reduced to 30 on each of these plots. And whilst the herbage on the unmanured plot comprises 17 graminaceous, 4 leguminous, and 32 miscellaneous or weedy species, that of Plot 9 includes only 15 graminaceous, 2 leguminous, and 13 miscellaneous species, and that of Plot 14 only 14 graminaceous, 3 leguminous, and 13 miscellaneous species.

But such, again, is the difference in the character of the two nitrogenous manures—ammonia-salts and nitrate of soda—in regard to their reactions upon the soil, and the consequent degree of rapidity and range of distribution of them or their products of decomposition within it, that they respectively encourage the development of species of widely different underground, as well as above-ground habit of growth. Thus, the dominant plants were very different on the two manured plots. Under the influence of the annual application of mineral manure and ammonia-salts, *Dactylis glomerata* (rough cock's-foot), *Agrostis vulgaris* (common bent-grass), *Festuca ovina* (sheep's-fescue), and *Poa pratensis* (common meadow-grass), among graminaceous plants, and *Rumex acetosa* (sorrel-dock), among the miscellaneous herbage, prevailed somewhat in the order of enumeration; whilst under the influence of mineral manure and nitrate of soda *Bromus mollis* (soft brome-grass), had become so prominent as to constitute probably about one-half the crop; *Poa trivialis* (rough meadow-grass) was also very prominent, *Holcus lanatus* (woolly soft-grass), *Festuca ovina* (sheep's-fescue), *Lolium perenne* (rye-grass), *Dactylis glomerata* (rough cock's-foot), *Avena flavescens* (yellow oat-grass), and among weeds *Anthriscus sylvestris* (wild beaked-parsley), coming next in order of prevalence. And, whilst the plants most encouraged by the ammonia-salts have a tufty habit of growth above ground, and a tendency to luxuriate within a limited range beneath the surface, some of those most favoured by the nitrate of soda, and especially under its influence, are very different in character, not growing in tufts, but producing comparatively uniformly dense herbage, with many stems, comparatively few root-leaves, and roots having a characteristically downward tendency, those of the *Bromus mollis* especially (which contributed such a large proportion of the whole crop) being strong and wiry, and descending far into the subsoil.

The sectional examinations, indeed, showed great differences in the character of the turf, in the prevalence and character of development of the roots within and below it, and in the character of the soil and subsoil, as the following brief abstract of the observations made will show. It should be first stated, however, that whilst on the square yard selected as characteristic of the unmanured plot, there were found 9 graminaceous, 4 leguminous, and 11 miscellaneous species—in all 24; on that of Plot 9, having mineral manure and ammonia-salts, there were only 6 graminaceous, no leguminous, and only 3 miscellaneous species; and on that of Plot 14, receiving mineral manure and nitrate of soda, again only 6 graminaceous, only 1 leguminous, and 2 miscellaneous species.

Owing to the great complexity of the herbage on the unmanured plot, including a comparatively large number of leguminous, and miscellaneous or weedy species, some fleshy roots were observed at a considerable depth. The turf consisted of a complex network of fine roots and fibrils, which were much less in size and strength than in the case of either of the manured plots. These fine roots seemed to have more or less complete possession of the soil to a depth of about 6 inches, and some of them then showed a downward tendency; becoming, however, much fewer, and even in the second and third 9 inches extremely fine; and at a depth of about 40 inches they were as fine as a fibre of silk or a spider's web. It was concluded, though not with great certainty, that the roots found at the greatest depth were those of *Agrostis vulgaris* and *Bromus mollis*. The sample of the first 9 inches of the unmanured soil possessed the character of mould not much less than that of the manured plots; the second 9 inches was also very much altered from the character of the clay subsoil; but below this point very slight difference was observable; though, of the four lower samples, the uppermost, that is, the third from the surface, perhaps showed slightly the least, and the lowest, or sixth, the brightest red tinge.

The turf of Plot 9, manured with mineral manure and ammonia-salts, consisted of a dense, almost peat-like mass, of decomposing roots, radicle leaves, and stubble, thickly penetrated with strong roots and fibrils, the whole being as much matted as on the unmanured soil, showing, however, less complexity, but greater strength of roots. The horizontal subterraneous stems of the *Agrostis vulgaris* greatly predominated, emitting many fibrils, and sending out many descending fibrous roots. *Poa pratensis* also developed a large amount of strong root, and a profusion of fibrils. Roots penetrated to about the same depth as on Plot 3, but in larger quantity, and of larger size; being, however, in the fifth 9 inches, both very few in number and very fine. As already said, the samples of the first 9 inches of the soil of the three plots differed comparatively little from one another in the degree of their change by the action of vegetation; but, if anything, that of this Plot 9 was the darkest, indicating so far more of mould-like character. The second 9 inches of this plot was decidedly more changed than that of the unmanured, or of even Plot 14. The third and fourth 9 inches were, compared with the unmanured, slightly darker, or less bright in colour, showing still some change. The fifth and sixth were little, if at all, distinguishable in colour from the raw, reddish-yellow clay of the unmanured plot at corresponding depths.

The turf of Plot 14, manured with mineral manure and nitrate of soda, had not the peaty appearance of that of Plot 9; the prevailing plant, *Bromus mollis*, which made up about half the crop, possessing comparatively few radicle leaves; whilst, especially under the influence of this manure, *Poa trivialis*, *Holcus lanatus*, and *Lolium perenne*, have a tendency to assume the same character of development above ground. The *Bromus mollis*, too, was found in a most striking degree to send down strong wiry roots into the subsoil, leaving only its fibrils, and the roots of less prominent or smaller species, to feed near the surface. The second 3 inches of soil also held together, being full of fibre. At the extremity of the fibrils of the *Bromus mollis* small tubercles, much like those which occur on the roots of some leguminous plants, were observed down to a depth of perhaps 12 or 14 inches. The roots of this grass extended, however, to a depth of nearly 4 feet, still maintaining their wiry character. The difference in the character of the samples of soil, and especially of the subsoil, of this compared with those of either of the other plots, was very striking. The first 9 inches differed little from that of the unmanured plot. The second was, however, more altered than that of the unmanured plot at the corresponding depth. The third, fourth, fifth, and sixth 9 inches were very strikingly different in appearance from the corresponding layers of either of the other two plots; the clay, instead of being of a comparatively uniform reddish yellow colour, was very much mottled or veined, showing a mixture of yellow, grey, red, and brown, with the yellow and grey predominating. So much was this the case that when the samples were powdered they were of a yellowish grey colour, instead of reddish yellow; and the lighter or less yellow the greater the depth of the sample, that of the sixth 9 inches being the lightest of all.

There was, perhaps, more of natural grey vein in the subsoil of this than in that of the other plots, but the difference in colour and texture was too great to be so accounted for. Upon the whole the lower layers were softer and more soapy than in the case of either Plot 3 or Plot 9; though, as Table III. at page 98 shows, they contained a considerably less percentage of moisture. Indeed, the subsoil of this plot had much more the appearance of disintegration from some cause than that of either of the others; it was consequently much more easily worked, and especially more so than that of the unmanured plot, which was very tough and hard.

To sum up these distinctions: it is seen that not only did different plants become dominant according to the different condition of the plot as to manure, but those which prevailed on the unmanured land, though numerous, had much finer and much less vigorous roots; the raw clay of the subsoil was much less changed; and it had yielded up very much less moisture to the growing crop. On the plot manured with mineral manure and ammonia-salts free-growing grasses predominated; but chiefly those whose underground habit of growth was such as rendered them dependent for their food and moisture in great measure on that which is to be found in the upper layers of the soil. Still, owing to the increased vigour of growth under the influence of the manure, it is seen that moisture was obtained, either directly by the roots of the plants, or by capillary action induced by the pumping out of the upper layers, from the extreme depths to which the samples were taken; and, from the great difference in the percentage of moisture at that depth compared with that of the unmanured plot, there is no doubt that the action extended deeper still. On Plot 14, on the other hand, where nitrate of soda was applied, the plant which contributed about half the produce had roots of a very characteristically downward tendency. We find the soil, to the depths examined, pumped drier still; and, coincidently, the drought has comparatively little affected the amount of the crop.

Intimately connected with the greater change in the subsoil of the plot manured with nitrate of soda than in that manured with ammonia-salts, with the greater predominance and luxuriance of the deeper-feeding herbage, and with the consequent little evil effects from the drought where the nitrate was employed, is doubtless the fact that the ammonia of the ammonia-salts is much more readily absorbed and retained by the soil than is the nitric acid of the nitrate. The latter, consequently, becomes, under the influence of rain, more rapidly distributed and washed into the subsoil, whither the roots follow it. As this filtration, into and through the subsoil, of a solution of the nitrate, or of its products of decomposition within the soil, has been proceeding for thirteen years in succession, there is little cause for surprise that the subsoil should have become much more changed than where the ammonia-salts had been used. It seems intelligible, too, that those plants of the herbage, whose habit of growth is characterised by a comparatively large development of descending roots, aided as they would be when once they had asserted their predominance by more and more self-sowing each succeeding year, should get such complete possession of the lower layers of the soil, with their stores of food and moisture. On this point it may be remarked, that the *Bromus mollis*, which so strikingly predominated on the nitrated plot, and whose roots, though only a biennial, had obtained more complete possession of the subsoil than those of any other plant, is one of the earliest of the grasses, and has, in point of fact, generally seeded to a greater or less extent before the crop has been cut.

It may be here mentioned in passing, that, wherever, in the course of the experiments at Rothamsted, nitrate of soda is employed year after year on the same plot of arable land, the difference in the appearance and texture of the soil is very great, and is discernible at a considerable distance. The soil apparently retains very much more moisture, becomes more agglutinated, and so sticky compared with that of adjoining plots under equal conditions of weather, as to be with difficulty worked at the same time, and never brought to the same tilth without the expenditure of extra labour upon it. It may be judged, indeed. that during the wet season the nitrated soil, and its more disintegrated subsoil, would acquire more moisture, or at least more available moisture, than the soil and raw clayey subsoil of the other plots.

We have, then, in the properties of the nitrate of soda and its effects upon the soil and subsoil, in the influence of these in determining the character of the prevailing herbage, and in the comparative independence of external sources of moisture which a deep root range gives to the plants encouraged, an explanation of the fact that, notwithstanding the unusual drought of 1870, which almost suspended the growth of the unmanured herbage, and much diminished that manured with mineral manure and ammonia-salts, the plants which had gradually asserted possession over others on the plot continuously manured with mineral manure and nitrate of soda, should have yielded, under the same circumstances of scarcity of rain, an all but average crop.

Before leaving the subject of the influence of the drought of 1870 on the hay-crop, it may be added that a portion of the park adjoining the experimental plots was liberally manured with London stable-dung, but no benefit whatever was apparent, and the crop was so light as to be scarcely worth mowing.

The evidence at command in regard to the effects of the drought on other of the experimental crops, is not of the same, or in some respects of so direct a kind, as that relating to the mixed herbage, and to the soils, of the experimental plots of grass land. Nevertheless, some facts of interest may be recorded illustrating the influence of the moisture stored up within the soil on the growth of both wheat and barley.

Results relating to the Growth of Wheat.

The following Table (IV.) shows the amounts of grain, and the amounts of total produce (corn and straw together), obtained in the experimental wheat-field for 19 years in succession, 1852-1870 inclusive:—

1. On Plot 3, continuously unmanured.
2. On Plot 2, receiving 14 tons farmyard manure per acre per annum.
3. On Plot 7, receiving, annually, mixed mineral manure, and 400 lbs. ammonia-salts per acre.
4. On Plot 9a, receiving, annually, the same mixed mineral manure as plot 7, and 550 lbs. nitrate of soda per acre.

The Table also shows, side by side with the amounts of produce, the fall of rain each year during the months of April, May, June, and July, which may be said to include the period of active vegetation and accumulation of substance. It should be further explained, that, in order that the different amounts of grain from year to year may be more strictly comparable one with another, and to avoid the necessity of recording and considering the weight per bushel in each case, the total weight of dressed corn has been divided by 61, and the Table shows, therefore, not the actual number of measured bushels in each case, but the number of bushels of an assumed uniform weight of 61 lbs.

TABLE IV.—Produce of Wheat by different Manures, and fall of Rain during the 4 Months of active growth each Year, for 19 Years, 1852—1870.

Years.	Dressed Corn. (In Bushels of 61 lbs.) Plot 3. Without Manure.	Plot 2. Farmyard Manure.	Plot 7ab. Mineral Manure and Ammonia-salts.	Plot 9a. Mineral Manure and Nitrate Soda.	Mean.	Total Produce. (Corn and Straw.) Plot 3. Without Manure.	Plot 2. Farmyard Manure.	Plot 7ab. Mineral Manure and Ammonia-salts.	Plot 9a. Mineral Manure and Nitrate Soda.	Mean.	Rain at Rothamsted. April.	May.	June.	July.	Total.
	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	lbs.	lbs.	lbs.	lbs.	lbs.	Inches.	Inches.	Inches.	Inches.	Inches.
1852	12 7/8	26 1/4	24 1/2	(1)	21 1/4	2457	5173	5440	(1)	4357	0·52	1·84	4·70	2·28	9·34
1853	4 3/8	16	20 1/8	(1)	13 1/2	1772	4492	5101	(1)	3788	3·00	1·73	3·47	4·49	12·69
1854	20 7/8	42 1/8	46 1/8	(1)	36 3/8	3496	7125	8497	(1)	6373	0·49	4·38	0·77	0·86	6·50
1855	16 1/2	35 1/4	32 1/8	28 3/8	28 1/8	2859	6082	6146	5878	5241	0·41	2·32	1·65	6·97	11·35
1856	12 7/8	34 7/8	34 7/8	30 3/8	28 1/4	2450	6594	6757	5894	5424	2·61	4·70	1·91	1·48	10·70
1857	19	40 3/4	44 3/8	43 1/8	36 7/8	2813	5910	6628	6634	5496	2·16	1·10	2·21	1·61	7·08
1858	17 7/8	39 7/8	39 3/4	37 3/8	33 3/4	2811	6349	6519	6701	5595	2·58	2·55	0·96	3·19	9·28
1859	15 3/4	33 1/2	31 3/4	26 3/4	27	3226	7073	6833	7076	6052	2·70	2·09	2·72	3·02	10·53
1860	11 1/8	29 3/8	24 5/8	27 5/8	23 1/4	2197	5304	4675	6635	4703	1·94	4·30	6·26	1·99	14·49
1861	10 5/8	34 5/8	33 3/4	31 3/8	27 5/8	1990	5303	5751	6607	4913	1·28	1·04	2·98	3·19	8·49
1862	15 1/8	38 3/8	34 7/8	42 3/8	32 3/4	2709	6642	6143	8738	6058	2·84	2·91	3·41	1·80	10·96
1863	17 3/4	45 1/2	55	56 5/8	43 3/4	2727	7165	9358	9888	7284	0·96	1·01	4·60	0·70	7·27
1864	16 3/4	41	47 3/8	52 1/8	39 3/8	2428	6488	7970	9315	6551	1·25	1·88	1·79	0·89	5·81
1865	13 1/4	37 3/8	40 5/8	44 1/8	33 7/8	1861	5484	6249	7563	5289	0·47	3·05	0·63	2·93	7·13
1866	12 1/8	33	29 7/8	32 1/4	26 7/8	2046	6128	5775	7377	5314	1·95	1·24	4·51	3·01	10·71
1867	8 1/8	27 3/4	22 1/8	28 5/8	21 5/8	1505	4891	4179	6773	4337	2·82	3·35	1·06	4·10	11·33
1868	16 5/8	42 1/8	39 7/8	47 7/8	36 5/8	2027	6794	6317	8150	5822	2·19	0·73	0·37	0·37	3·66
1869	13 1/8	35 1/8	26 3/4	36 1/2	28	2198	6193	4972	7298	5165	2·18	3·23	1·07	0·97	7·40
1870	15 1/8	38	42	46 3/4	35 1/2	2002	5092	5836	6851	4946	0·46	1·35	0·98	1·12	3·91
Averages	14 1/4	35 3/8	35 1/4	38 1/2 (1)	30 3/4	2398	6016	6267	7336(1)	5406	1·72	2·36	2·43	2·37	8·88

(1) In 1852, 1853, and 1854, there was no mineral manure employed on plot 9*a*, and the amounts of nitrate used were less than the quantity mentioned in the text. Hence the produce is not given for those years; and the average produce by the mineral manure and nitrate is taken over 16 years only.

The evidence afforded by the results in the foregoing Table is confessedly quite inadequate to show what are the climatic conditions favourable or otherwise to the growth of wheat. It is, however, quite sufficient for our present purpose, which is to illustrate the comparative independence of the crop on the mere amount of rain falling during the period of active vegetation. It will suffice to call attention to a few of the more extreme examples.

The four years of largest total fall of rain over the four months in question were, 1853, 1855, 1860, and 1867, and three of them were also the seasons of smallest average crop, both of corn and total produce, whilst the fourth (1855) was a season of generally less than the average produce. On the other hand, the three years of highest produce, both corn and total produce, were 1854, 1863, and 1864, and all three were seasons of less than the average fall of rain during the four months of active growth. Lastly, the two seasons of lowest fall of rain during April, May, June, and July were 1868 and 1870; and both gave, with each of the four conditions as to manure, more than the average produce of corn over the nineteen years; and in 1868, though not in 1870, there was even more than the average of total produce also, under each of the three manured conditions. But although there was in both these years of great deficiency of rain during the growing period, more than the average produce of corn without manure, there was, in both, less than the average amount of both straw and total produce.

As in the case of the hay crop, so again with the wheat, it is seen that, whilst during the earlier years the mineral manure and ammonia-salts gave more produce, both corn and total produce, than the mineral manure and nitrate of soda, during the later years the nitrate has given more, and sometimes considerably more, of straw especially, than the mineral manure and ammonia-salts. The questions arise, how far may this be due: to the more rapid and more extended distribution of the nitrate of soda, or its products of decomposition, within the soil and subsoil? to the mutual reactions of the manure and the soil? to the greater power of retention of moisture acquired by the latter, as the result of such reaction? and to more active root development in the spring under these conditions?

Unfortunately, no comparative determinations of moisture in the soils of these two plots, or of root development, have been made, so as to obtain direct evidence in regard to the questions here suggested. Due weight should, however, be given to the fact that, whilst the ammonia-salts are sown in the autumn, before the seed, the nitrate is applied as a top-dressing in March. It is known that nitrate of soda, or its nitric acid in combination with some other base, distributes more rapidly, and, under equal circumstances as to rain, is more liable to be washed into the subsoil or the drains, than is the ammonia of the ammonia-salts. Hence it is not applied until the commencement of active growth, when the plant is able rapidly to avail itself of it. It is also known that a portion of the ammonia of the ammonia-salts itself becomes converted into nitric acid, and then is subject, in like manner, to loss by drainage; but to what degree a saturated condition of the soil during winter may cause serious loss, in this way, of the ammonia applied as ammonia-salts in the autumn, is a question not yet sufficiently investigated, and to which we shall make some further reference before concluding.

Although, as has been said, there is no evidence at command in regard to wheat, in reference to the questions above raised, so direct as that referring to the meadow land, yet the results now to be adduced nevertheless supply interesting and important data in respect to the variation in the amount of moisture within the soil at different depths, as affected by season, by manure, and by the growth of the crop.

Such were the drought and heat of May, June, and July, 1868, that it is hardly possible to suppose conditions more calculated to induce extreme dryness of soil than those preceding the harvest of that year. Accordingly, towards the end of July, just before the crop was ripe, samples of soil were taken from three plots of the experimental wheat-field, with the special view of determining the amount of moisture retained at different depths. The plots selected were:—

Plot 3. Without manure since 1839.

Plot 2. With 14 tons farmyard manure per acre per annum.

Plot 8*a*. With mixed mineral manure, and 600 lbs. ammonia-salts per acre per annum.

The mode of collecting the samples was that already described, excepting that the iron frames employed were only 3 inches deep, instead of 9; the object being to determine the amounts of moisture at each 3 inches of depth, down to a total depth of 36 inches, or rather below the pipe-drains.

The subsoil of the farm consists of a tolerably tenacious reddish-yellow clay, resting upon chalk, and the corn crops seldom suffer from a scarcity of rain. At the time the samples were taken, the wheat had suffered but little from the drought, as the results already quoted show. But barley and oats were exceedingly light crops, and a bean crop in an adjoining field was quite dried up and dead for want of moisture.

For comparison with these samples taken at a time of extreme dryness, others were collected from the same plots in January, 1869, after much rain during the preceding ten days;

the drains were running, and it was supposed that the ground was quite saturated. It was, indeed, so wet that it was necessary to lay down boards for the men to stand upon whilst working.

Table V., overleaf, shows the percentages of moisture in the different samples of soil; bringing together—first, the results for the three plots during the drought; second, those for the three plots when the land was saturated; and lastly, the same results arranged for the convenient comparison of the percentages in the dry state and the wet state, and showing the difference between the two, for each plot separately.

It will be obvious that the amount of water at the different depths in July, 1868, after about three months of great deficiency of rain, and the growth of a crop then approaching ripeness, must, in the main, be dependent on the supplies accumulated during the previous winter and early spring. But it is affected, to a greater or less depth from the surface: by any difference of texture and power of absorption, the result of previous cultivation, manuring, and cropping; by the influence of the pipe-drains, which are at a depth of about 30 inches; also, by the shade of the crop on the one hand, lessening evaporation from the soil itself, and on the other, by the requirements of the growing crop increasing, according to its amount, the exhalation through the plants themselves, and the consequent pumping out of the stores within the soil.

The soil of Plot 3, which had received no manure and produced little root (tending to disintegrate the soil and increase its absorptive surface), which had comparatively little shade from the growing plants, preventing surface evaporation, and whose crop would exhale comparatively little, is seen to retain a somewhat less percentage of water than either of the others within 3 inches of the surface, but more than either within the next 9 inches. In it, as in the others, the percentage of moisture increased gradually from that point downwards, until obviously affected by the action of the pipe drains.

The soil of Plot 2, which had then been manured with 14 tons of dung per acre per annum for twenty-five years in succession, notwithstanding the greater requirements of the crop, retained rather more moisture than the unmanured soil within 3 inches of the surface; a result partly due, perhaps, but not wholly, to more shade. But, from that point downwards, doubtless influenced by the requirements of the crop, the dunged soil retained less at every stage (excepting the lowest) than the unmanured.

The soil of Plot 8, manured annually with mineral manure and ammonia-salts, and yielding pretty uniformly a heavier crop

TABLE V.—PERCENTAGES of MOISTURE, in SUMMER and in WINTER, in the SOIL at different depths, of PLOTS in the EXPERIMENTAL WHEAT-FIELD differently manured.

Nos. of Samples; each 3 Inches deep.	Collected July, 1868.				Collected January 6–7, 1869.				Plot 3. Without Manure.			Plot 2. Farmyard Manure.			Plot 8a. Mineral Manure and Ammonia-salts.		
	Plot 3. Without Manure.	Plot 2. Farmyard Manure.	Plot 8a. Mineral Manure and Ammonia-salts.	Mean.	Plot 3. Without Manure.	Plot 2. Farmyard Manure.	Plot 8a. Mineral Manure and Ammonia-salts.	Mean.	Collected July, 1868.	Collected Jan. 6, 1869.	Difference.	Collected July, 1868.	Collected Jan. 7, 1869.	Difference.	Collected July, 1868.	Collected Jan. 6, 1869.	Difference.
1	4·05	4·48	4·31	4·28	21·43	39·67	26·53	29·21	4·05	21·43	17·38	4·48	39·67	35·19	4·31	26·53	22·22
2	7·20	7·01	6·07(1)	6·76	24·54	35·62	22·93	27·70	7·20	24·54	17·34	7·01	35·62	28·61	6·07(1)	22·93	16·86
3	8·91	7·38	6·66	7.65	24·35	28·85	20·62	24·61	8·91	24·35	15·44	7·38	28·85	21·47	6·66	20·62	13·96
4	10·65	8·14	8·45	9·08	21·41	23·95	24·07	23·14	10·65	21·41	10·76	8·14	23·95	15·81	8·45	24·07	15·62
5	11·24	9·98	12·44	11·22	22·07	20·59	24·84	22·50	11·24	22·07	10·83	9.98	20·59	10·61	12·44	24·84	12·40
6	13·20	12·26	14·34	13·27	21·48	21·07	24·79	22·45	13·20	21·48	8·28	12·26	21·07	8·81	14·34	24·79	10·45
7	14·03	12·51	15·20	13·91	21·82	26·96	23·69	24·16	14·03	21·82	7·79	12·51	26·96	14·45	15·20	23·69	8·49
8	15·09	12·91	16·86	14·95	23·59	24·87	28·98	25·81	15·09	23·59	8·50	12·91	24·87	11·96	16·86	28·98	12·12
9	16·84	13·78	17·98	16·20	24·74	25·75	27·01	25·83	16·84	24·74	7·90	13·78	25·75	11·97	17·98	27·01	9·03
10	18·03	13·45	18·53	16·67	25·71	25·34	28·59	26·55	18·03	25·71	7·68	13·45	25·34	11·89	18·53	28·59	10·06
11	14·64	14·49	17·67	15·60	23·97	25·18	28·93	26·03	14·64	23·97	9·33	14·49	25·18	10·69	17·67	28·93	11·26
12	15·44	16·11	16·85	16·13	22·94	22·75	27·40	24·36	15·44	22·94	7·50	16·11	22.75	6·64	16·85	27·40	10·55
Mean	12·44	11·04	12·95	12·14	23·17	26·71	25·70	25·19	12·44	23·17	10·73	11·04	26·71	15·67	12·95	25·70	12·75

(1) There was an error in the determination in this case; and the figure given is calculated on the assumption that the amount of the moisture in the second 3 inches would probably bear about the same relation to that in the first and third 3 inches as in the case of Plot 3.

than the dung, shows less moisture within the first 9 inches, and but little more within the next, or fourth 3 inches, than that of the dunged plot; also a total to that depth considerably less than the unmanured soil. From that point, however, there is a gradually increasing amount down to the range of the drains; notably more than in the dunged soil, and even more than in the unmanured, whose crop could only have withdrawn from it about one-third as much.

Supposing the three plots to have possessed exactly the same character of soil and subsoil, and to have contained the same amount of moisture to a given depth at the time of the commencement of active growth, we could well understand that, when the growth was nearly completed, the subsoil of the dunged plot, growing more than three times the crop, should contain less moisture than the unmanured subsoil. But, on the same suppositions, it would be difficult to account for the subsoil of Plot 8*a*, which grew even a larger crop than the dung, retaining not only more than the subsoil of the dunged plot, but more also than that of the unmanured plot. The differences between plot and plot as to percentage of moisture are, it is true, in some cases not great. But there is too much regularity and consistency in the results to admit of the supposition that the differences are due to errors arising from the unavoidable difficulties incident to the collection, weighing, and preparing the samples for drying, without some error of experiment affecting the estimation of the amount of water. The results relating to the soils and subsoils when supposed to be in a state of saturation will show, indeed, that the active growth of the crops probably did not commence with equal soil-supplies of moisture in the three cases.

The unmanured soil, when saturated, contained, to the depth examined, not much less than one-fourth its weight of water, and nearly twice as much as in the dry condition. The range of variation in the percentage was much less than in the dry soil; but, on the other hand, the order and degree of increase or decrease is much less regular in the wet soils. The top 3 inches contained rather less water than the second and third; otherwise, there would seem to be, at the time of saturation, more water near the surface, then a decreasing amount, and then a gradually increasing quantity, until the range of the drains is reached.

The dunged soil, with its vast accumulation of organic matter, and doubtless greater degree of disintegration, porosity, and power of absorption within some distance from the surface, is seen to hold about one and a half times as much water within the first 6 inches as the unmanured soil, or even as that manured with mixed mineral manure and ammonia-salts. The third 3 inches, also, contains more than either; and the fourth more than the unmanured, and about as much as the artificially manured soil. The quantity continues to diminish to the fifth 3 inches, and then increases to about the level of the drains. To the total depth examined, the dunged soil contained more than a quarter of its weight of water, about 3½ per cent. more than the unmanured, and about 1 per cent. more than the artificially manured soil.

The soil receiving mineral manure and ammonia-salts also retained more water within what may be called the staple than immediately below it. It then again increased in percentage of moisture, more or less regularly, until within the direct influence of the drains. It is to be observed, too, that, whether owing to a greater retentive power of the natural clay at that point, or more probably to the accumulation, and the action, of the constituents of the manures, or of their products of decomposition, rendering the clay more hygroscopic, the lower layers of the soil of this plot retained considerably more water when saturated than did the corresponding layers of either of the other plots. The amount of water to the total depth was about 2½ per cent. more than in the unmanured soil, but not so much as in the dunged soil.

As might be expected, there are greater irregularities of increase or decrease indicated in the percentages of water at the different depths, among the results relating to the saturated, than among those relating to the dry soils. This may be due in part to accidental differences of permeability of the soil, and consequently to variation in the freedom of access of the percolating water, at the different points; but it is, doubtless, partly due to unavoidable error in the collection, weighing, and after-manipulation, of soil in so wet a condition.

Disregarding the irregularities, however, and interpreting the obvious direction of increase or decrease of moisture at the different depths, it is pretty clear that, down to a certain depth from the surface—which varied in the different plots according to the varying power of retention of the staple and immediately subjacent layers—the increased percentage of moisture was due to the comparatively recent rains. There was then reached the layers partially drained since the preceding rains, from which point downwards the percentage increased, until again reduced by the action of the pipe-drains.

Further, it is obvious that, by evaporation from the surface, and the consequent withdrawal by capillary action of water from below upwards on the one hand, and by the gradual descent, aided by the natural drainage of the chalk and the artificial drainage of the pipes, on the other, what may be called the normal supply of water within the soil would, doubtless, at the commencement of active growth, be considerably less than that indicated by the percentages in the saturated soils. There is also good reason to suppose that, owing to the action of the manures, or their products of decomposition, within the soil and subsoil, the manured plots would retain more than the unmanured; and further, that whilst the effects of the dung would be chiefly to increase the retention by the upper layers, those of the artificial manures would be more characteristically to increase the amount retained by the lower layers.

This brings us to a comparison of the amount of water in each plot in the two conditions of unusual dryness and of saturation or abnormal wetness, as shown in the right-hand half of the Table V.

Referring first to the unmanured soil, there is seen to be a difference of more than 17 per cent. of moisture between the wet and dry conditions of the staple, or uppermost 6 inches of soil. The difference then diminishes, more rapidly at first, until, in the lower layers, it ranges from under 8 to about 9 per cent. There is an average of about $10\frac{3}{4}$ per cent. more water in the wet than in the dry soil to the total depth examined.

The difference between the saturated and the dry conditions of the various layers of the dunged soil is much more striking still: amounting to over 35 per cent. within the first 3 inches, to nearly 29 per cent. in the second 3 inches, to more than 21 per cent. in the third 3 inches, and to nearly 16 per cent. within the next, or fourth, 3 inches. It then lessens considerably, again increases, and again diminishes to within the range of the drain-pipes. The result is that, within the uppermost 12 inches of soil, there is an increase of about 25 per cent. of moisture in the wet as compared with the dry condition; or, taking the total depth of 36 inches, there is an increase of over $15\frac{1}{2}$ per cent.

The artificially manured soil also shows, almost throughout, greater difference in the amount of water retained in the two states than the unmanured, but less than the dunged soil. In the lower layers there are, as in the case of the dunged plot, some irregularities not satisfactorily explained. The final result, to the total depth of 36 inches, is an average of nearly 13 per cent. more water in the wet than in the dry condition.

It will be useful to compare the actual amounts of water per acre, in the different soils to the total depths examined, which the percentage results represent. Reckoning, as before, the soil in the dry state to weigh, exclusive of stones, an average of 1,000,000 lbs. per acre for each 3 inches of depth, we have 12,000,000 lbs. for the weight of the dry soil to the depth of

36 inches; and allowing one-eighth more for the wet soil, we have 13,500,000 lbs. per acre for its weight to the depth of 36 inches. Adopting these figures, and the average percentage of moisture in the soil of each plot, we have the following amounts of water per acre on the respective plots in the two conditions:—

TABLE VI.

	July, 1868. Dry.	January, 1869. Saturated.	Difference.
Tons of Water, per Acre, to a depth of 36 inches.			
Plot 3.—Unmanured	666	1396	730
Plot 2.—With Farmyard Manure	591	1610	1019
Plot 8*a*.—With Mineral Manure and Ammonia-salts	694	1549	855
Tons of Water, per Acre, over (or under) Plot 3.			
Plot 2.—With Farmyard Manure	−75	214	289
Plot 8*a*.—With Mineral Manure and Ammonia-salts	28	153	125

Thus we have on the unmanured plot 730, on the dunged plot 1019, and on the artificially manured plot 855 tons, more water per acre, to the depth of 36 inches, when the soils were saturated than when in the dry condition. As already said, the soils would not retain such an amount of moisture at the time of the commencement of active vegetation. But, by way of illustration, it may be stated that if they retained even two-thirds of the indicated difference prior to the commencement of the drought, and the commencement of active growth in 1868, the amount would be considerably more than would be required by the unmanured crop, and would supply a large proportion of that required by the manured crops, on the supposition that about 300 parts of water would be exhaled by the plants for 1 part of dry substance fixed by them. The soil-resources of moisture available to the growing crop would, however, doubtless extend beyond the depth to which the examinations refer. Then, again, the amount of rain which actually fell during the period of active growth, though comparatively small, would, nevertheless, be not immaterial considered in relation to the balance of the requirements of the crops.

A very remarkable point connected with these results is, however, the difference in the amount of water retained per acre to a given depth by the soils of the different plots when saturated.

The unmanured soil and subsoil, comparatively little disturbed and disintegrated by the permeation and the decomposition of roots, and not at all by the action of manures, would offer less surface and absorb less water, and they are seen to retain less than those of either of the manured plots. The soil and subsoil of the artificially manured plot would be affected by the permeation not only of more roots, but of the solution of the manures or of some of their products of decomposition,—by the latter especially in the lower layers. But it is the dunged plot, with its vast accumulation of organic matter near the surface, and its finely divided and dissolved products of decomposition permeating to a greater or less depth beyond, and, doubtless, a considerable development of root, that is seen to possess the greatest power of retention of moisture, especially near the surface.

Taking the figures relating to the saturated soils as they stand, the artificially manured plot retained 153 tons, and the dunged plot 214 tons more water per acre, to the depth examined, than the unmanured—amounts which represent, respectively, about $1\frac{1}{2}$, and more than 2 inches of rain. Or, if we take the difference between the amounts retained in the dry and the wet conditions, the dunged soil shows a still greater excess of absorption when saturated, both compared with the unmanured, and with the artificially manured soils. Further, the details show that the dunged soil, when saturated, retained, within 12 inches of the surface, an excess of water which would be equivalent to about $1\frac{1}{2}$ inch of rain more than that held to the same depth on either of the other plots.

In connection with this interesting fact, it may be mentioned, that whilst the pipe-drains from every one of the other plots in the experimental wheat-field run *freely*, perhaps on the average four or five times annually, the drain from the dunged plot seldom runs at all more than once a year: indeed, it has not with certainty been known to rnn, though closely watched, since about this time last year. At first it was thought that there must be some stoppage, or some fault in the levels. Accordingly, the soil was opened in various places, but was found to be far from saturated down to the range of the drains. It was then concluded that the result was due to the greater power of absorption and retention of moisture by the dunged soil near the surface; and even supposing the figures above given should exaggerate the difference actually occurring, there would still be a wide margin remaining, sufficient to account for the fact of no water reaching the drains excepting under the influence of an unusually large and continued rainfall. Such a fact as the one here recorded is obviously of great interest and significance. Whether the porosity of a clay soil be increased by the application of manure, by mechanical means, or by a combination of the two, its power to absorb and retain water, without being wet, and in an available state, will be proportionately increased, and the necessity for artificial drainage, at any rate on some soils, would be greatly obviated.

From the results adduced, it may safely be concluded, as already intimated, that the three plots would retain different amounts of water, due to the previous winter rains, at the time of the commencement of active vegetation in the spring. And although the actual amounts of excess indicated by the figures in Table VI. may not be true measures of the increased retention by the manured as compared with the unmanured soil, and although the excess at any one time may not be sufficient to meet the increased requirements of the manured crop, it must be supposed that the soils of higher retentive power would retain proportionally more of every heavy shower falling from time to time during growth ; and hence may be accounted for the differences, not at first sight adequately explained, in the amounts of water retained by the different soils at the period when they had supported, and nearly carried to completion, such widely different amounts of crop.

Have we not, also, in the fact that the soil and subsoil, to a considerable depth, may frequently during the winter be saturated with water, a probable explanation, of part at least, of the less effect of a given amount of nitrogen applied in the autumn in the form of ammonia-salts, than of an equal amount supplied in the spring as nitrate of soda? For although the ammonia of the ammonia-salts is in great part absorbed by the upper layers of the soil, it is well established that a portion of the nitrogen supplied as manure in the form of ammonia becomes converted into nitric acid, and reaches the drains in the form of a nitrate; and it may be assumed that this action would, other things being equal, be the greater the greater the amount of water passing through the soil. Professor Voelcker, who has analysed many of the drainage waters collected at different times from the several plots in the experimental wheat-field at Rothamsted, has, moreover, found a greater amount of nitric acid in them the greater the amount of ammonia-salts applied as manure.

Another reason which may in part explain the frequent less effect of a given amount of nitrogen applied as ammonia-salts than of an equal amount applied as nitrate of soda, even when both are sown at the same time in the spring, may be that, as the nitric acid of the nitrate distributes more rapidly under the influence of rain than does the ammonia of the ammonia-salts, so may the development of root be the more encouraged under the influence of the nitrate; and so, proportionately, will the plant gain greater possession of the soil, and consequently be able to avail itself of a wider range of both food and moisture within a given time. Further, from the results which have been recorded on the point in the foregoing pages, it would seem that when the nitrate is applied year after year on the same plot for many years in succession, the action on the soil and subsoil of its solution, or of that of the products of its decomposition, tends to increased disintegration, and to increased power of retention of moisture, and thus, again, to encourage a greater extension of root.

Results relating to the Growth of Barley.

Our next and last illustrations have reference to the growth of barley. This crop has been grown at Rothamsted for nineteen years in succession on the same land, without manure, with farmyard manure, and with numerous artificial mixtures each year. The fluctuations in the amount of produce dependent on season, manure, and the continued growth of the crop, being greater than in the case of wheat, it would occupy too much space to follow up the same line of illustration as that adopted in regard to that crop; and it is the less necessary or desirable to do so, as we hope to report the whole of the results after the twentieth crop in succession has been harvested.

Referring to the influence of the variation of rainfall from year to year, it will suffice to say here that extremely low produce of barley was obtained with both a great excess and a great deficiency of rain during the months of active vegetation. The bad result with excess of rain was coincident with unusually low, or unusually high temperatures; and that with deficiency of rain with high temperatures. On the other hand, the highest amounts of produce were obtained with only moderate amounts of rain during the growing period, provided there were a favourable distribution of it, and a favourable adaptation of temperature. And whilst an excess of rain, during the growing months, is adverse to the favourable growth of both wheat and barley, a great deficiency of rain during that period is found to be, as would be anticipated, more adverse to the spring-sown barley than to the winter-sown wheat.

In the experiments on barley, equivalent amounts of nitrogen, as ammonia-salts and nitrate of soda respectively, have not been employed in conjunction with mineral manures from the commencement; but where they have been employed, each separately, without such admixture, a similar result is observed as with both hay and wheat. That is to say, higher amounts of both corn and total produce have been obtained from the use of a given amount of nitrogen applied as nitrate of soda, than from that of an equal amount applied as ammonia-salts—both manures being in the case of barley sown in the spring.

In 1868 experiments were commenced in which nitrate of soda was used in conjunction with mineral manures, and below are given the results obtained in 1868, 1869, and 1870, with mixed mineral manure and 200 lbs. of ammonia-salts per acre per annum, compared with those of the same mixed mineral manure and 275 lbs. of nitrate of soda, which is estimated to contain about the same quantity of nitrogen as the ammonia-salts. As in the case of wheat, not the actual number of bushels measured, but the bushels of dressed corn calculated at an assumed uniform weight per bushel are given. For barley, 52 lbs. per bushel is taken.

TABLE VII.—Showing the effects on the Barley Crop of a given amount of Nitrogen as Ammonia-salts, compared with an equal amount as Nitrate of Soda.

	DRESSED CORN. (In bushels of 52 lbs.)		STRAW.		TOTAL PRODUCE. (Corn and Straw.)	
	Mineral Manure and Ammonia-salts.	Mineral Manure and Nitrate Soda.	Mineral Manure and Ammonia-salts.	Mineral Manure and Nitrate Soda.	Mineral Manure and Ammonia-salts.	Mineral Manure and Nitrate Soda.
	Bushels.	Bushels.	lbs.	lbs.	lbs.	lbs.
1868 ..	37	49	2333	2868	4311	5454
1869 ..	$54\frac{3}{8}$	$54\frac{7}{8}$	3853	4265	6701	7194
1870 ..	$41\frac{3}{4}$	$48\frac{7}{8}$	2090	2050	4287	4621
Mean	$44\frac{3}{8}$	$50\frac{7}{8}$	2759	3061	5100	5756

Here, then, we have again a similar result. There is, too, proportionately a greater increase with the nitrate, especially of corn, in the two drier and hotter seasons of 1868 and 1870—years, in fact, of summer drought.

The following Table shows the produce of barley without manure, with farmyard manure, and with mixed mineral manure and 200 lbs. ammonia-salts per acre, in 1868, and in 1870, the two recent years of summer drought; and also, under the same conditions as to manure, the average produce over the nineteen years of the experiment. As before, the number of bushels of dressed corn, reckoned at an uniform weight of 52 lbs. per bushel, is given. And, side by side with these records of produce, is given the amounts of rain at Rothamsted, in April, May, June, and July, each year, those being the months of active growth of the barley crop.

TABLE VIII.

	Dressed Corn. (In bushels of 52 lbs.)				Total Produce. (Corn and Straw).				Rainfall at Rothamsted.				
	Without Manure.	Farmyard Manure.	Mineral Manure and Ammonia-salts.	Mean.	Without Manure.	Farmyard Manure.	Mineral Manure and Ammonia-salts.	Mean.	April.	May.	June.	July.	Total.
	Bush.	Bush.	Bush.	Bush.	lbs.	lbs.	lbs.	lbs.	Ins.	Ins.	Ins.	Ins.	Ins.
1868	11⅛	47⅞	37⅛	32	1902	5281	4311	3831	2·19	0·73	0·37	0·37	3·66
1870	13⅞	52⅛	41¾	35⅞	1489	4949	4287	3575	0·46	1·35	0·98	1·12	3·91
Average, 19 Years, 1852–1870 ..	20	50¼	48⅛	39½	2453	5856	5786	4698	1·72	2·36	2·43	2·37	8·88

As there has been a decline in the produce without manure during the latter as compared with the former half of the period over which the experiments have extended, the difference indicated between the unmanured produce in the years of drought and that over the nineteen years will exaggerate the deficiency due to the deficient rainfall alone during the four growing months of the two years in question. On the other hand, the produce by farmyard manure has considerably increased during the latter half of the period, and hence the deficiency in the years of drought which the figures show for that manure is less than is due to the characters of the seasons alone. With the artificial manure the produce was, however, very much more nearly equal during the first and second halves of the total period, and the indicated deficiency in the years of drought probably more nearly represents that really due to the characters of the seasons in its case. With this manure there was a deficiency compared with the average, of 11 bushels of corn in 1868, and of 6⅜ bushels in 1870; or, of total produce, of 1475 lbs. in 1868, and of 1499 lbs. in 1870. There was not far from an equal total amount of rain during the four months in the two seasons; but whilst there was more than an average fall in April, 1868, and only about one-fourth the average fall in April, 1870, there was a greater deficiency in May, June, and July, 1868, than in the same months in 1870. The result was a greater deficiency of corn, but a less deficiency of straw, in 1868 than in 1870.

We are enabled to adduce more direct experimental evidence showing the extent to which the barley-plant can avail itself of the stores of moisture within the soil, than that which was at command relating to wheat.

Before considering the results themselves, to which reference is here made, it will be well to describe briefly the circumstances under which they were obtained. With a view to the determination of what proportion of the rainfall passes to given depths in the subsoil, under different conditions of season, manuring, and cropping, a series of experiments has been commenced, for the cutting off, and the collection, of the drainage-water from the land at different depths—an essential condition being that neither soil nor subsoil should be disturbed. Leaving out of view for the present the questions of the influence of different manures, or of the growth of different crops, early in 1870 three plots of uncropped land, each of one-thousandth of an acre area, were selected, with a view of determining the amount of water passing below the depths of 20, 40, and 60 inches, respectively. The plan of operating was, to cut a sufficiently wide trench for men to work in, down one side of the plot, to a considerably greater depth than that at which the drainage was to be cut off. The plot was then carefully undermined and shored up at the depth decided upon, until a cast-iron plate, rather more than the length of the plot, 8 inches wide, and having small holes for the water to drain through, could be got in and fixed underneath. The plot was then further undermined, until another plate could be put in; and so on, until the whole was supported at the proper depth, without disturbance, by a perforated iron flooring, which finally was itself supported on three sides by brickwork, and on the fourth and across the middle by iron girders. The three as yet undisturbed sides of the plot were then trenched round; a 4½-inch brick and cement wall was built round the plot, resting on the projecting rim of the iron flooring below, and finished level with the surface above. The trench outside the wall was then filled in again. Thus, the exact area required was cut off from the surrounding soil by brickwork at the sides, and below, at the depth required, by a perforated iron flooring.

The field in which these *drain-gauges* were made, had grown wheat in 1869, and was sown with barley in March, 1870, and the drill by mistake was allowed to sow two rows of seed on the plots along one side of them. As the excavations proceeded, barley-roots were observed to have extended to a depth of between 4 and 5 feet, and the clayey subsoil appeared to be much more disintegrated, and much drier, where the roots had penetrated than where they had not. Accordingly, it was decided to make careful notes on the sections under the two conditions, and also to take samples of soil and subsoil to a depth below that at which roots were traced, with a view to the determination of the amounts of moisture at the different depths in the two cases. Portions of the barley-ground and the fallow-ground, closely adjoining the drain-gauge plots, but undisturbed by the excavations in connection with them, were selected, and from each six samples, 6 × 6 inches superficies by 9 inches deep, that is, in all to a depth of 54 inches, were taken.

The following Table shows the percentages of moisture in the different samples, including that lost during their preparation, as well as that afterwards expelled at a temperature of 212° Fahr. :—

TABLE IX.—Percentages of Moisture in Uncropped and in Cropped Land, at different depths.

Samples collected June 27th and 28th, 1870.

Depth of Sample.	Fallow Land.	Barley Land.	Difference.
First 9 inches	20·36	11·91	8·45
Second 9 ,, ...	29·53	19·32	10·21
Third 9 ,, ...	34·84	22·83	12·01
Fourth 9 ,, ...	34·32	25·09	9·23
Fifth 9 ,, ...	31·31	26·98	4·33
Sixth 9 ,, ...	33·55	26·38	7·17
Mean	30·65	22·09	8·56

Before commenting on these results, it should be stated that, ten days previous to the collection of the samples, about two-thirds of an inch of rain had fallen, and only three days before the collection about one-tenth of an inch; and hence, perhaps, may in part be accounted for the somewhat high percentage of moisture in both soils near the surface at that period of a season which was upon the whole one of unusual drought. Further, for a few days during the interval since the heavier rainfall, some soil, thrown out from the excavations near, had laid upon the spot whence the samples from the uncropped land were taken, and hence, again, may be accounted for part of the excess near the surface in the uncropped as compared with the cropped land.

The difference between the amounts of water retained at the depths examined by the uncropped and the cropped ground, at points only a few feet apart, is very striking; and that it should be greater in the upper portions of the subsoil, which had probably contributed more to the exigencies of the growing crop than the lower layers, is what would be expected. The percentage of water in the subsoil even of the cropped land was very high—indeed nearly as high at corresponding depths as in that in the experimental wheat-field in January, 1869, when it was supposed to be in a state of saturation; whilst the amount in the subsoil of the uncropped land was not only considerably higher than in that of the cropped land, but considerably higher also than in that of the saturated wheat soil. We shall recur presently to the difference in the percentage of moisture in the soils and subsoils of the different fields which have been referred to, but must first direct attention to the more special application of the results now under consideration.

The following Table shows the number of tons of water per acre retained to the total depth of 54 inches, or 4½ feet, by the uncropped and the cropped land, and the difference between the two. The upper line gives the amounts calculated according to the actual weights of the measured samples of soil (exclusive of stones), and the lower line the amounts, assuming that (exclusive of stones), the dry or barley soil would weigh 18, and the wet, uncropped or fallow soil 19½ million lbs., to the depth of 54 inches:—

Table X.—Tons of Water per Acre to the depth of 54 inches, in Fallow Land, and in Land Cropped with Barley.

Samples collected June 27th and 28th, 1870.

	Water per Acre.		
	Fallow Land.	Barley Land.	Difference.
	Tons.	Tons.	Tons.
According to experimentally determined weights of soil	2875	1951	924
According to assumed average weights of soil	2668	1775	893
Mean	2772	1863	909

On whichever basis the calculation is made, the indication is that there were about 900 tons less water per acre in the soil and subsoil, to the depth of 4 feet 6 inches, where the barley had grown than where the land was fallow. It may be, that part of the excess in the uncropped land was due to the shelter from surface evaporation since the last preceding heavy rain, by the laying of soil upon it for a few days, as above referred to. But even supposing a liberal deduction on this account, the evidence would still point to the conclusion that there had been a higher rate of exhalation by the growing crop than 300 parts of water for every 1 part of dry substance fixed; for it may safely be assumed that the dry matter of the crop at the time of the experiment would be under rather than over 2 tons per acre, which, at the rate of 300 parts to 1, would only account for an exhalation of 600 tons of water per acre. Further, since there was such a great difference in the percentage of moisture in the two cases at the lowest depth taken, it is only reasonable to conclude that the difference extended lower still.

To conclude, in reference to these particular experiments, it is clear that we have in the facts adduced sufficient evidence, and a striking illustration, of the enormous extent to which, in a time of drought, our crops may rely upon the supplies of moisture previously stored up within the soil. At the same time it cannot fail to be recognised how dependent must be the result upon the character of the soil and the subsoil with which the farmer may have to deal.

Summary, and General Observations.

Leaving detail, it will be of interest to summarise the results illustrating the difference of effect of the drought of the past year on the different crops, and also to bring together those relating to the amount of water retained by the soils and subsoils of the different fields, under the various conditions as to season, manuring, and cropping.

It has been already said that although the summers of both 1868 and 1870 were seasons of drought, yet, chiefly owing to the facts that the deficiency of rain commenced later, and the temperatures ruled higher in 1868, there was in reality considerable difference in the characters of the periods of growth of the two seasons, and in their consequent effects upon the different crops. To save space, however, we will confine attention here to the effects on the different crops of the more continued drought of 1870.

Table XI. shows the average annual produce obtained, under selected conditions as to manure, of hay, of wheat, and of barley; also the produce of each in 1870, and the deficiency compared with the average. In the case of the hay, the average is taken over 15 years, and in that of wheat and barley over 19 years. For simplicity of comparison, the produce is, for all three crops, given in lbs.; and the figures relating to wheat and barley represent the total produce, corn and straw together—which, of course, more clearly indicates the total amount of vegetable growth, compared with that of the hay, than the records of corn and straw separately would do.

TABLE XI.—Produce of Hay, Wheat, and Barley in 1870 compared with the average.

	Hay; 15 Years.	Total Produce, Corn and Straw. Wheat; 19 Years.	Barley; 19 Years.
Without Manure.			
	lbs.	lbs.	lbs.
Average produce per acre per annum	2391	2398	2453
Produce in 1870	644	2002	1489
Deficiency in 1870	1747	396	964
With Farmyard Manure.			
Average produce per acre per annum	4604*	6016	5856
Produce in 1870	1556	5092	4949
Deficiency in 1870	3048	924	907
With Mixed Mineral Manure and Ammonia-salts.			
Average produce per acre per annum	5794	6267	5786
Produce in 1870	3306	5836	4287
Deficiency in 1870	2488	431	1499

It is remarkable that, notwithstanding the great fluctuation in the amounts of produce of each of the three crops from year to year according to season, and also the difference in the degree in which each will vary from the average in one and the same season, still, when the average is taken over a considerable number of years, hay, wheat, and barley, are seen to yield *without manure* almost identically the same average weight of produce per acre per annum. On this point it should be mentioned that the second crop of grass is never removed from the land, being either consumed on it by sheep having no other food, or mown and left to rot as manure. The deficiency without manure, due to the drought of 1870, is seen to be 1747 lbs. of hay, 964 lbs. of barley (corn and straw), and only 396 lbs. of total produce of wheat. Thus, the deficiency was much the greatest in the hay; there being a reduction in its case by nearly three-fourths, in that

* For the hay crop, farmyard manure was only applied in the first 8 years; but the average produce is taken over the 15 years.

of the barley by scarcely two-fifths, and in that of the wheat by only about one-sixth, compared with average amounts.

For the hay-crop, farmyard manure was only applied during the first 8 years of the 15; but as the average produce was as great over the succeeding 6 years without the manure, as over the first 8 years with it, and as there was a heavier crop in 1869 than in any of the preceding 13 years, the deficiency in 1870 compared with the average, may be taken as at any rate mainly due to the drought, and but little to the cessation of the manuring. The figures as they stand show, as without manure, again, a much greater deficiency than in either wheat or barley; the crop amounting in fact to only one-third the average. Of total produce of wheat and barley, there is, with farmyard manure, again nearly the same average amount over 19 years in the two cases. The deficiency in 1870 compared with the average is also very nearly the same with the autumn-sown wheat and the spring-sown barley; amounting in each case to scarcely one-sixth. In the wheat the reduction is actually much greater, but in proportion to the average, only about the same as without manure; but in the barley it is actually less, though in proportion to the average very much less, than without manure. The greater power of retention of water which a dunged soil has been shown to possess in its upper layers, has doubtless much to do with the result.

With the artificial mixture in the case of the hay and the wheat supplying 400 lbs., but in that of the barley only 200 lbs. of ammonia-salts per acre per annum, there is not the same uniformity in the average annual produce of the three crops; the wheat giving nearly 500 lbs. more gross produce than the hay with the same amount of ammonia applied, and the barley about the same as the hay, with only half the supply of ammonia-salts. The deficiency in 1870 amounts, in the hay to more than two-fifths, in the barley to rather more than one-fourth, and in the wheat to little more than one-fifteenth, compared with the average.

Thus, then, with a drought extending over the months of April, May, June, and July, the mixed herbage of permanent meadow land suffered, under the different conditions of manure in question, very much more than either wheat or barley; and the spring-sown barley suffered, both without manure and with the artificial manure, very much more than the autumn-sown wheat. With the farmyard manure, however, the barley would appear to have been as little adversely affected by the deficiency of rain during the period of actual growth as the wheat. We need not here again refer to the special conditions already explained, under which the hay crop was as little, or less, affected by the drought than the other crops.

The difference between the conditions of growth of the chiefly perennial (or biennial) plants composing the complex mixed herbage of permanent meadow land, and those of an annual, like wheat or barley, sown at a stated period of the year in arable land, and having a fixed, and in the case of barley only a limited time for distributing its underground feeders, and so availing itself of the resources of nutriment and moisture within the soil, are obviously very great.

The perennial, or biennial, character of most of the plants composing the mixed herbage, would seem at first sight to give the grass a great advantage over the corn crops. But observation shows, that although the immediately superficial layers of the soil may be more thoroughly penetrated by the roots of the perennial grasses than by those of either wheat or barley, yet it is only a very few of the former, encouraged to great predominance only under special conditions, that seem to get anything like the same possession of the lower layers of the soil as the two corn crops. Careful examination has also shown, and it is probably generally assumed, that the winter-sown wheat secures possession by its underground feeders of a more extended range and greater bulk of soil, and consequently is better able to avail itself of the supplies of food and moisture existing below a certain limited depth from the surface, than the spring-sown barley. The wheat-plant, indeed, has the advantage of making root, more or less according to season and manure, throughout the winter months, during periods of which, at any rate, the soil will be saturated with moisture; and in the case of moderately retentive and well drained soils, it will be able to establish its independence of rain falling during the period of active aboveground growth, very much more than will a spring-sown crop like barley.

But there are other points of distinction between the growth of the corn and the hay crops. Thus, most of the grasses, which comprise the greater proportion of the latter, flower earlier than the wheat or the barley; and the mixed herbage is cut by, or before, the end of June, when very little, if any of it, has arrived at the degree of ripeness in which the corn crops are cut. These, on the other hand, are not only allowed fully to ripen, but direct experiments made at Rothamsted upon wheat have shown that a very large proportion, probably about half, of the total dry vegetable substance, or of the total carbon of the crop, is fixed in it under the influence of the greater power of the sun's rays after the time at which the hay crop is usually cut.

These facts are obviously an element in the explanation of another fact, to a certain extent commonly recognised, and which a careful comparison of the results of the field experiments at

Rothamsted, with the records of the conditions of heat and moisture under which the crops have been grown, brings clearly to view—namely, that, as compared with the hay crop, the corn crops are not only less dependent on the amounts of rain falling during the period of active vegetation, but more on a relatively high degree of temperature during that period. This is more strikingly the case when wheat is grown by means of readily soluble mineral and nitrogenous manures, than when it is grown without manure, or with farmyard manure. Without manure the produce is comparatively more dependent on the amount of certain constituents brought down by the rain, or rendered available by its means from the stores of the soil itself; and it would seem that where farmyard manure is employed, a considerable amount of rain is required during the early growing period to aid its decomposition, and so to set free, distribute, and render available, its fertilising constituents. In the case of the artificial manures, on the other hand, some of the most active fertilising constituents are supplied in a much more soluble form, and require a less amount and continuity of rain for their solution and distribution throughout the pores of the soil within a given range.

It is seen, then, that several reasons concur to render corn crops less dependent on the fluctuations in the amount of rain falling during the period of active vegetation and accumulation of substance than is the hay crop growing under otherwise parallel conditions as to soil and manure. It is quite intelligible, too, that the autumn-sown wheat, with its much longer time for the formation and distribution of root, and its tendency to develop proportionally more in the lower and proportionally less in the upper layers of the soil, than the spring-sown barley, should be less adversely affected than the latter by a deficiency of rain during the period of active above-ground growth.

Table XII. brings together at one view the percentage amounts of water retained by the soils and subsoils of the different fields, under the various conditions as to season, cropping, &c. The results so summarised relate to samples collected as under:—

1. From the experimental wheat field, just before harvest, 1868; mean of three plots differently manured.

2. From the experimental wheat field, in January, 1869, when the land was supposed to be saturated; mean of the same three plots differently manured.

3. From uncropped land, near the end of June, 1870.

4. From land cropped with barley, closely adjoining the uncropped land; samples collected at the same date, end of June, 1870.

5. From permanent meadow land, in July, 1870, after the removal of the crop; mean of three plots differently manured.

TABLE XII.—Summary of Percentages of Moisture in Soils and Subsoils from different Fields, and under different conditions as to Season, Cropping, &c.

Depths of Samples.	EXPERIMENTAL WHEAT FIELD.		BARN FIELD. Samples collected, June 27th and 28th, 1870.		PERMANENT MEADOW LAND.
	Samples collected, July, 1868; Mean of Plots 3, 2, and 8*a*.	Samples collected, Jan. 6th and 7th, 1869; Mean of Plots 3, 2, and 8*a*.	Uncropped Land.	Land Growing Barley.	Samples collected, July 25th and 26th, 1870; Mean of Plots 3, 9, and 14.
First 9 ins.	6·23	27·17	20·36	11·91	11·99
Second 9 ,,	11·19	22·70	29·53	19·32	11·77
Third 9 ,,	15·02	25·27	34·84	22·83	17·11
Fourth 9 ,,	16·13	25·65	34·32	25·09	19·32
Mean 36 ,,	12·14	25·19	29·76	19·79	15·05
Fifth 9 ,,	..	..	31·31	26·98	20·67
Sixth 9 ,,	..	..	33·55	26·38	21·49
Mean 54 ,,	..	..	30·65	22·09	17·06

The special application of the detailed results having been already fully considered, attention must be confined here to the more general indications only of the foregoing summary.

In the first place, it should be observed that all three fields have a subsoil of reddish yellow clay, resting upon chalk, at a varying depth, but of not many feet from the surface. All, therefore, have good natural drainage; and it is very seldom that any water collects in the furrows, and then only for a very few hours. The experimental wheat field is, however, pipe-drained at a depth of about 30 inches, and at a distance of about 25 feet from drain to drain.

It is of interest to observe that there is no wide difference in the amount of water retained at corresponding depths in the experimental wheat-field in July 1868, when the crop was nearly at maturity, and in the permanent meadow land in July 1870, after the removal of the hay crop. The percentages are, however, rather lower in the drained land; which, at the time, had probably supported a higher average amount of produce also.

Towards the end of June 1870, the undrained arable land, which then carried a crop of growing barley, representing perhaps from $1\frac{1}{2}$ to 2 tons of dry substance fixed, retained only about the same amount of water near the surface as the meadow land in July 1868; but, lower down, it held considerably more than either the drained wheat land in July 1868, or the undrained meadow land in July 1870.

It is remarkable that the uncropped and undrained land, though retaining much less water within 9 inches from the surface, from that point downwards retained, in June 1870, considerably more at every stage than the drained wheat soil in January 1869, when the drains were running, and the land was supposed to be saturated. From this comparison, it is obvious that no safe conclusion can be drawn from the percentage of water in the subsoil of the uncropped but undrained land, as to the probable amount retained by the subsoil of the drained land at the commencement of active vegetation in the spring. The amount retained in the subsoil of the uncropped and undrained land is indeed enormous; but the comparison of it with that in the adjoining cropped land shows clearly enough that it was readily available for the purposes of vegetation. In reference to this latter point, the fact of the good natural drainage by the chalk must not be overlooked.

There is, upon the whole, general consistency in the results brought together in Table XII. It may, perhaps, safely be concluded that, notwithstanding the natural drainage by the chalk, the pipe-drains had contributed to reduce the percentage of moisture retained by the subsoil of the experimental wheat field, to the depth examined; but that they had, at the same time, rendered the clay more permeable by roots, and the water that was retained more readily available. The evidence is, at any rate, very striking as to the degree in which, in a time of drought, our crops are enabled to rely upon the water previously accumulated within the subsoil—provided the latter be of sufficient depth, of sufficient retentive power, and at the same time sufficiently permeable.

Before concluding, it will be well to call attention to a very important bearing of some of the results adduced. Assuming, as we may be allowed to do for the sake of illustration, that a good crop of hay, wheat, or barley, will probably exhale not less, and perhaps more, than 700 tons of water per acre during growth, we still have only about 7 inches of rain, out of an average annual fall of say 25 inches, thus directly disposed of by the growing crop; and, taking the amount retained by the soil itself as practically a constant quantity from year to year, there remains to be disposed of by evaporation from the surface, and by passage into the drains or otherwise beyond the reach of the roots of the crop, an average of about 18 inches of rain annually, equivalent to more than 1800 tons of water per acre.

How much of this large quantity of water passes off by evaporation from the surface of the soil itself, inducing by capillary action the withdrawal of water, carrying with it, it may be, essential plant-food, from the lower to the upper layers of the soil?—or, how much passes downwards, carrying in solution any manurial matters in excess of the quantity which can be absorbed and retained within the pores of the soil and the upper layers of the subsoil?

These questions cannot be so satisfactorily answered in regard even to any particular soil, or season, as is desirable; and could they be so, the answers would vary greatly with variations of soil and season. As already stated, direct experiments are now in progress at Rothamsted with the view of acquiring useful data on this subject. With regard to the results hitherto obtained, it may be remarked that, from September 1st to December 31st, 1870, that is, commencing after the unusual drought of the preceding summer, it was found that, out of a rainfall of about 10·5 inches within the same period, about 50 per cent. had passed below a depth of 20 inches, about 40 per cent. below 40 inches, and about 20 per cent. below 60 inches from the surface. Calculation further showed that, even supposing there were some accumulation during August, still, a very large proportion of that which did not so pass, would be required to bring the previously very dry soil to the point of saturation—judging this requirement from the results which have been already given bearing upon the point. That is to say, as would be expected, a comparatively small proportion of the rainfall was evaporated at that season of the year. Much more would, of course, so disappear taking the whole year round; the quantity varying considerably with the characters of the soil and the season.

Towards the end of the last century, Dr. Dalton * devised an apparatus for the determination of the proportion of the rainfall which passed off from the soil by drainage, and by evaporation, respectively. It consisted of a cylinder 10 inches in diameter, 3 feet deep, open at the top, and closed at the bottom; but having one small exit tube near the top, and another near the bottom, for the escape of water into bottles placed to receive it. The vessel was filled with earth, and sunk into the ground level with the surface, one side being left exposed for access to the bottles. He continued the experiment for three years, 1796-7-8, and found the drainage to average, over that period, 25 per cent., and the evaporation to be, therefore, equal to 75 per cent. of the rainfall. This was exclusive of any evaporation of dew, but inclusive of that resulting from vegetation, as the surface of the soil became, after the first year, covered with grass; a circumstance which, however, Dr. Dalton considered immaterial.

For eight years, 1836-1843, Mr. Dickinson, of Abbott's Hill, King's Langley, Herts,† experimented with a modification of Dalton's apparatus. The cylinder he employed was 12 inches in diameter, and 3 feet deep, but provided at that depth with a perforated bottom, and a receptacle beneath for the collection of

* Mem. Lit. Phil. Soc. of Manchester, vol. v., part 2.

† 'Journal of the Royal Agricultural Society,' vol. v.

the water; and there was an arrangement of tubes for the escape, and measurement, of the drainage water. Grass was grown on the surface of the soil in the cylinder. The drainage would doubtless be more free in the experiments of Mr. Dickinson than in those of Dr. Dalton; and the results, over 8 years, showed, with a less rainfall, a larger actual amount of drainage; the latter representing 42½ per cent., and the evaporation, therefore, only 57½ per cent. of the rainfall. This amount included, of course, the exhalation due to vegetable growth.

From results obtained by gauging the flow of water from pipe-drains, it has been concluded that a still larger proportion of the rainfall passes off by evaporation than that indicated by the experiments of either Mr. Dickinson or Dr. Dalton. But results obtained by deducting the amount passing through drains from the total rainfall may be judged to be quite untrustworthy, from the fact that, before the pipe-drains in the experimental wheat field had passed any water at all in the autumn of last year, the *drain-gauges* already referred to had indicated that, of the rain which had then fallen since the 1st of September, nearly 25 per cent. had passed below 20 inches, nearly 10 per cent. below 40 inches, and nearly 4 per cent. below 60 inches from the surface. It is clear, therefore, that the amount of water passing through artificial drains may be no measure whatever of the total quantity passing below the reach of the roots of growing crops.

In the admitted defect of satisfactory evidence from which may be deduced the probable average amount of evaporation from the surface of the soil independently of vegetation, we will assume, by way of illustration, that, taking the average of many soils and seasons, three-fourths of a total rainfall of 25 inches will pass off by the combined action of evaporation from the surface of the soil itself, and of the exhalation due to the growth of a good crop of hay or corn. On this supposition there would still remain more than 6 inches of rain, equivalent to more than 600 tons of water per acre, annually passing downwards, and carrying with it more or less of fertilising matters.

Fortunately, some of the most important mineral constituents of soils and manures are, in the case of the heavier soils at any rate, almost wholly retained by them within the range of the roots of our crops. Nitrogen, whether supplied in the form of ammonia-salts or nitrates, is, however, much less completely so retained, being, in whichever state supplied, carried off in greater or less quantity in the drainage water, chiefly in the form of nitrates. According to results obtained independently by Professor Frankland and Professor Voelcker, on the analysis of drainage water from the experimental wheat field at Rothamsted, that collected during the winter, from land manured in the autumn by an amount of ammonia-salts supplying 82 lbs. of nitrogen per acre, may contain from 2·5 to 3 parts, or even more, of nitrogen, as nitrates and nitrites, per 100,000 parts of water. Assuming that only 2·5 parts of nitrogen were so carried beyond the reach of roots for every 100,000 parts of water passing downwards, there would still be, for every inch of rain so passing, a loss per acre of between 5 and 6 lbs. of nitrogen, supplied in manure at a cost of not much less than 1*s.* per lb.

The above estimate of quantity must be understood to be adopted only provisionally, and by way of illustration. It is, however, a sufficiently near approximation to what must happen in the case of many soils and seasons at any rate, to show the very great importance of further investigating the reactions of various descriptions of nitrogenous manure on different descriptions of soil, and of determining the best modes, and the best periods of the year, for the application of such manurial matters, so as to reduce the loss by drainage to a minimum. This subject is now receiving attention at Rothamsted.

Rothamsted, January, 1871.

VI.—*Description of Ordinary and Improved Kilns for Burning Lime for Agricultural Purposes.* By CHARLES TURNER, C.E.

PRIZE ESSAY.

I. THE COMMON PERPETUAL KILN.

A KILN for burning lime, for agricultural purposes, is generally placed in the side of a chalk or limestone hill, to avoid expense in brickwork or masonry. The kiln itself, in its cheapest form, is an inverted truncated cone from 12 to 15 feet in diameter at the top, excavated out of the chalk or limestone rock, and lined on the inside with good hard bricks, capable of withstanding a considerable amount of fire. The lining should be from $1\frac{1}{2}$ to 2 bricks thick, according to the size of the kiln, and filled in solidly at the back with hard chalk or limestone, set in mortar.

In the best kilns of this construction, the side walls are built upright for about 4 feet in depth, and then the cone is gradually tapered off to a diameter of 3 feet at the draught or draw-hole. The height of the cone is generally equal to the diameter at the top.

An arched opening is constructed in the exterior wall in front of the ash-pit, which should be sufficiently high to allow of a man standing upright, in order that he may get conveniently at the ends of the fire-bars when the lime is required to be drawn. Two strong cast-iron bars, called bearing-bars, 3 in. by $2\frac{1}{2}$ in., are fixed into the brickwork in such a manner that they can readily be withdrawn when required: upon them lie the wrought-iron fire-bars (which should be circular in section, for a reason which I